Practical Data Mining: Lessons Learned From the Barnett Shale of North Texas

SEG Shale Gas Technology Forum

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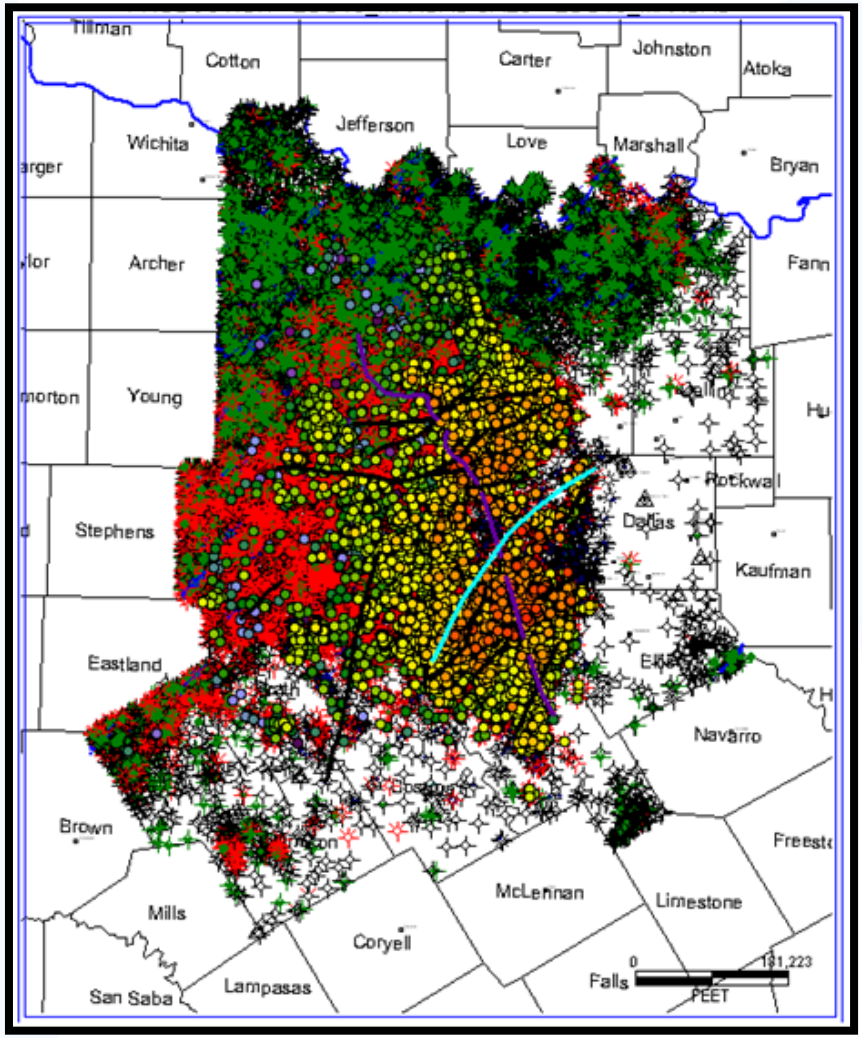
BAKER HUGHES

Introduction: SPE 140524

- Study objectives
- Database preparation
- Overview of Barnett production
- Tarrant / Johnson County Area of Interest (AOI)
  - Drift Angle and Azimuth
  - Well bore undulation
- Bonus Slides – Building on Tuesday's Sessions
- Conclusions

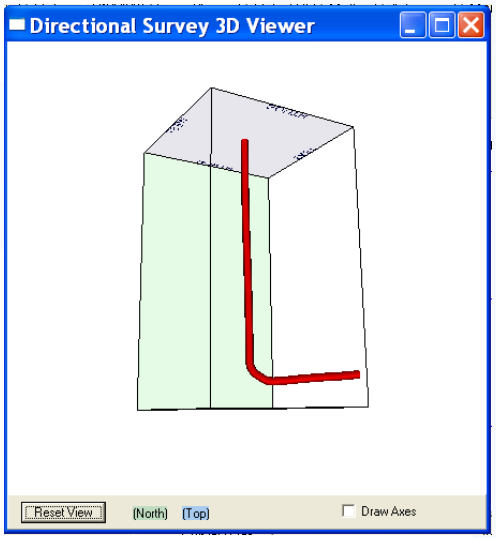
Study Objectives

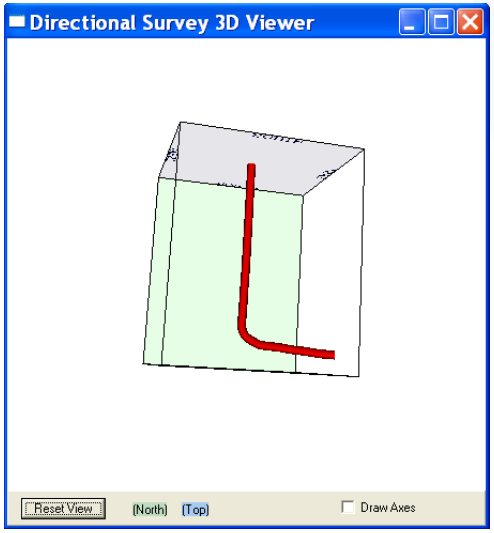
- Document ongoing reservoir quality, well architecture, completion, stimulation studies
- Provide for data-driven discussion of best practices



Database Preparation

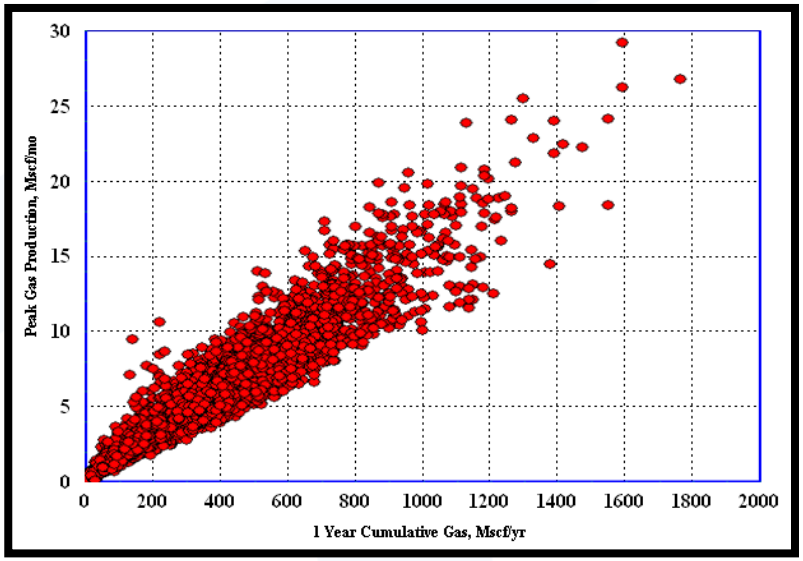
- Commercial data sets
  - Well history
  - Completion & stimulation practices
  - Monthly production
  - 3,300+ directional surveys
- Collected, reviewed, put into a database
- Quality Control Process
  - Statistical removal of outliers
  - Known limits & ratios examination





Overview of Barnett Production

- Development of Production proxies
  - Peak monthly gas rate
  - 3 & 12 month cum gas
    - 3 or 12 producing months cum beginning with peak month



7,310 wells, 2003-2009, R^2=.94

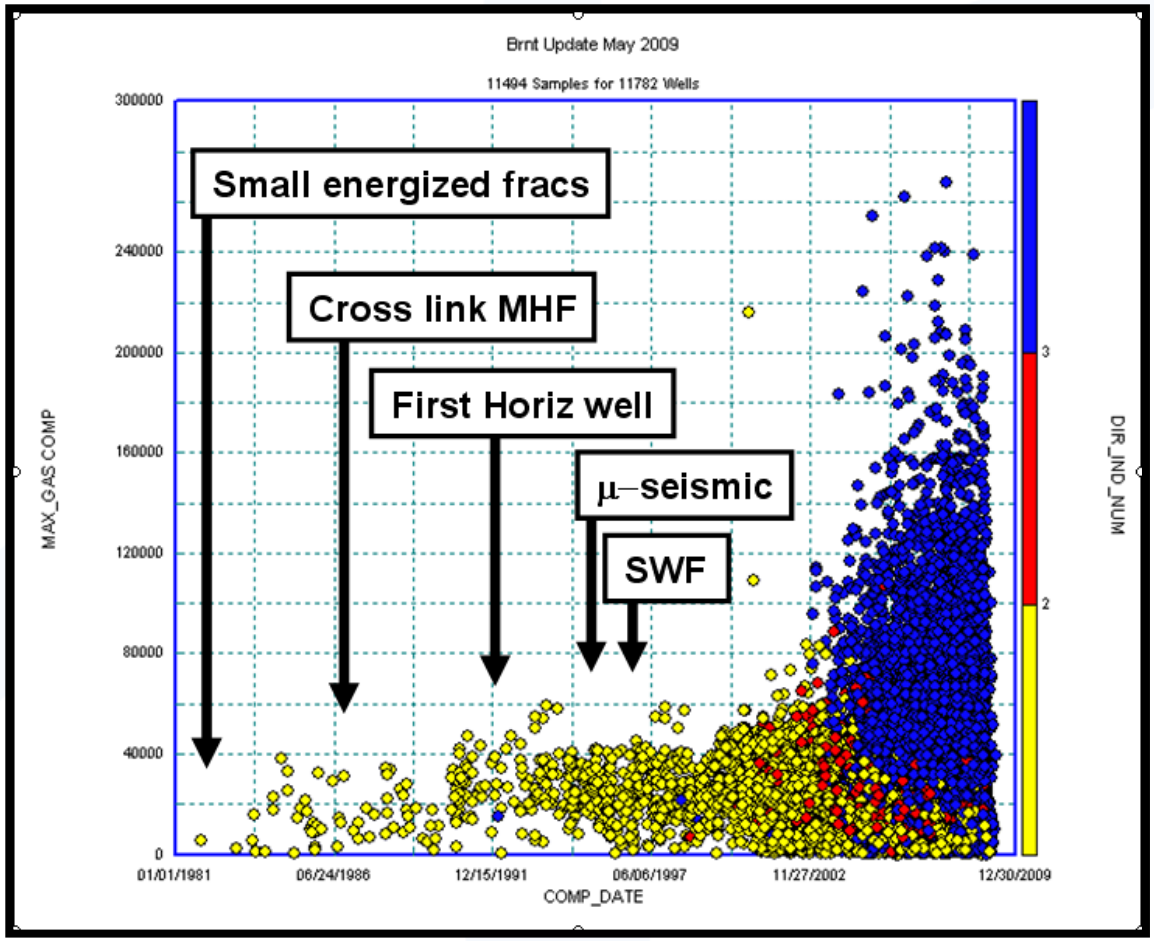
Well Architecture, Completion & Stimulation Time-Dependence

Average Statistics for Barnett Horizontal Completions						
	Completion Year					
Parameter	2004	2005	2006	2007	2008	2009
Number Completions	255	697	1239	2303	2662	1380
Perforated Length, ft	1793	1874	2054	2187	2363	2675
Peak Monthly Gas, Mscf/mo	52098	53150	49851	52640	54098	58689
1 year Cumulative Gas, MMscf/yr	378.3	355.2	325.2	340.2	358.4	365.2*
1 year Cumulative Liquids, BBl	2267	2048	1552	1469	1911	2438*
1 year Cumulative Water, BBl	44050	63915	64825	73026	89721	77329*
Treatment Volume, Mgal	3849	3793	3686	3353	3587	3796
Treatment Volume /perf ft, gal/ft	2206	1951	1779	1497	1418	1410
Proppant Quantity, Mlbs	1141	1400	1867	2287	2562	2624
Proppant Quantity /perf ft, lbs/ft	672	711	886	995	993	953
Number of Stages	2.1	2.8	4.0	3.2	3.2	3.6
Peak Monthly Gas P10, MMscf/mo	17.0	17.3	17.3	17.4	19.0	21.2
Peak Monthly Gas P25, MMscf/mo	29.1	27.4	26.5	27.9	30.3	34.2
Peak Monthly Gas P50, MMscf/mo	45.6	46.6	42.0	45.4	47.4	53.7
Peak Monthly Gas P75, MMscf/mo	69.6	68.2	64.1	68.8	69.2	74.9
Peak Monthly Gas P90, MMscf/mo	93.1	98.6	93.1	96.8	95.9	103.3

* Limited Sample size

Table 1 – Statistical Data for Whole Field Barnett Horizontal Completions 2004 to 2009

Production Result Time Dependence



Longer Is Better (Until It's Not)

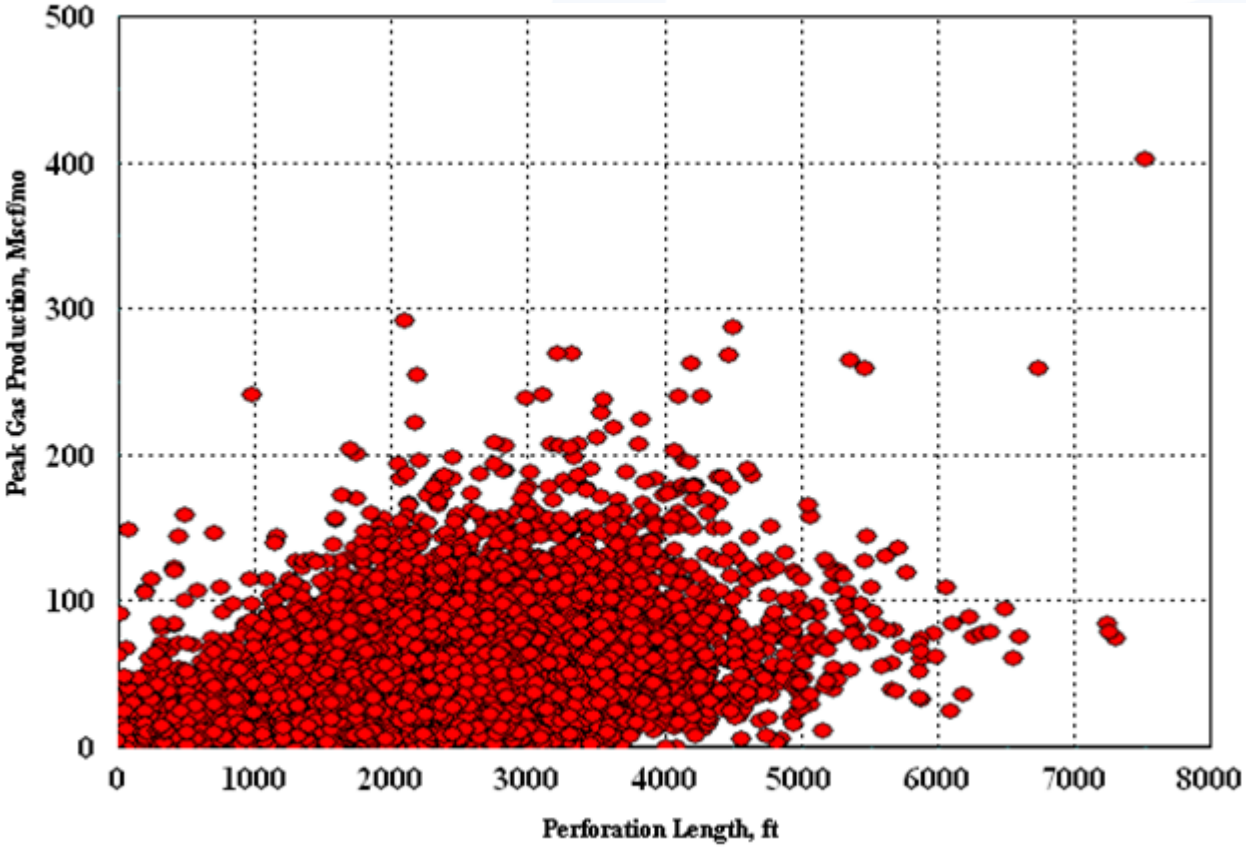


Figure 4 - Peak Monthly Gas rate vs. Perforated Length

GIS Mapping: WGR

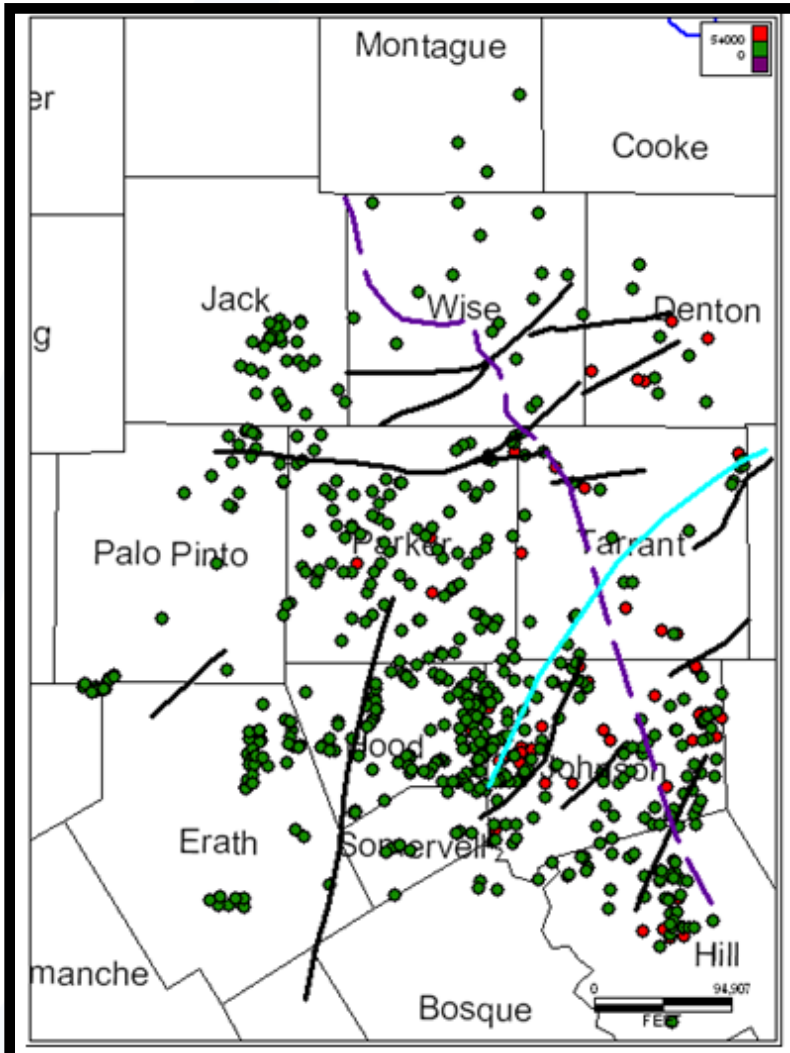


Figure 6 – Location Highest 10 percent 1 Year Water to Gas Ratio

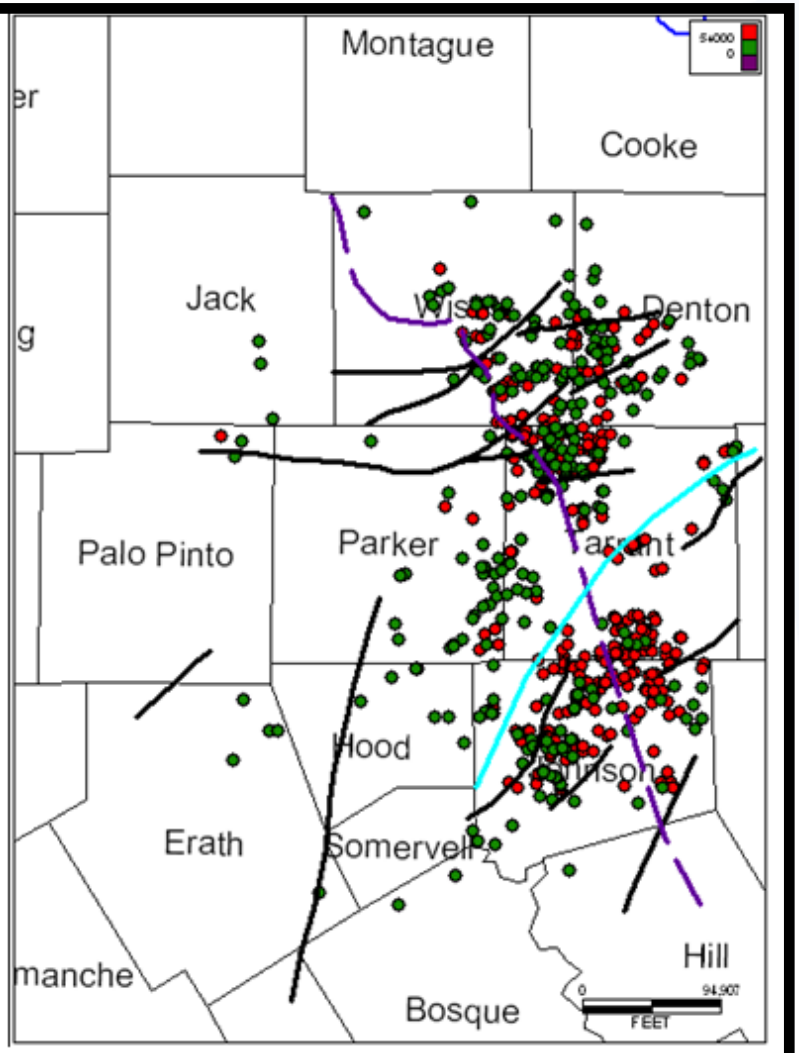


Figure 7 – Location Lowest 10 Percent 1 Year Water to Gas Ratio

Lowest 10% vs Best 10% Barnett Horiz Producers

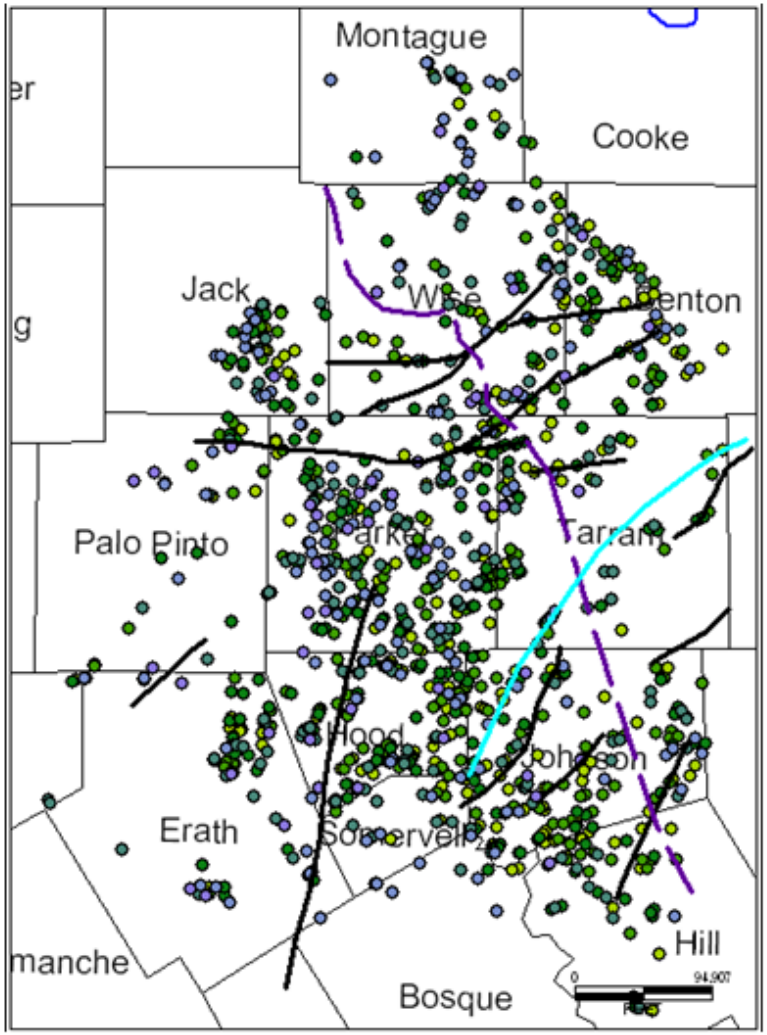


Figure 8 - Location of lowest 10 Percent of peak producers

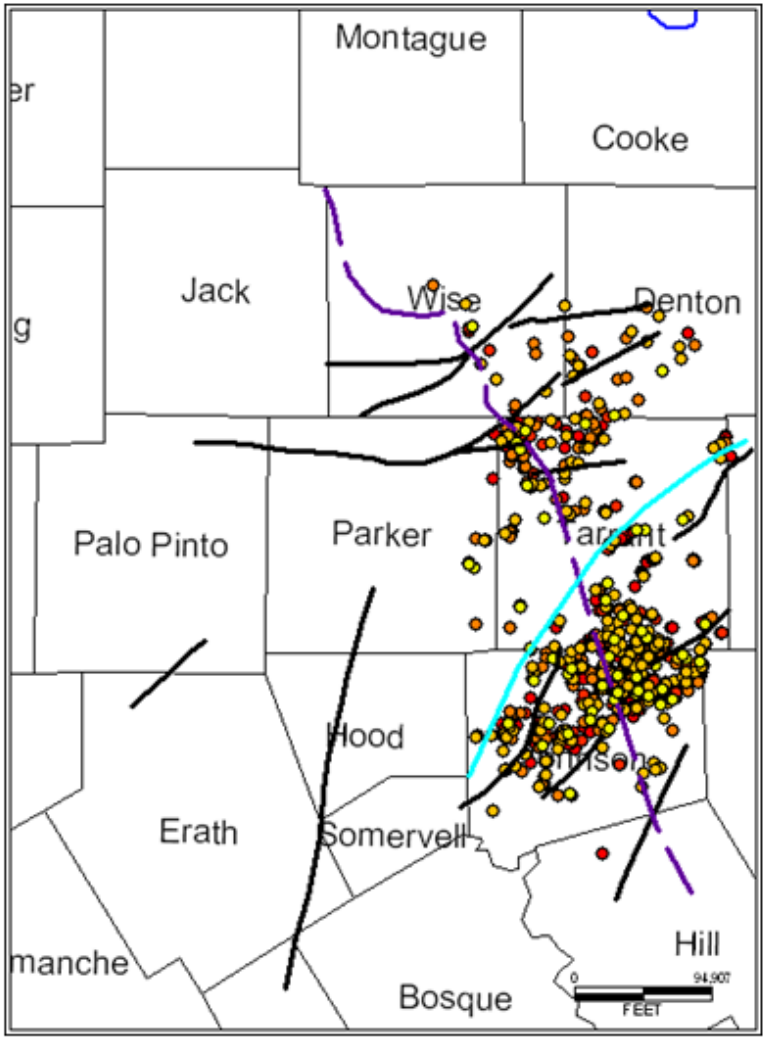


Figure 9 – Location of top 10 Percent of peak producers

Most Barnett Wells Do Not Have a Good Sump

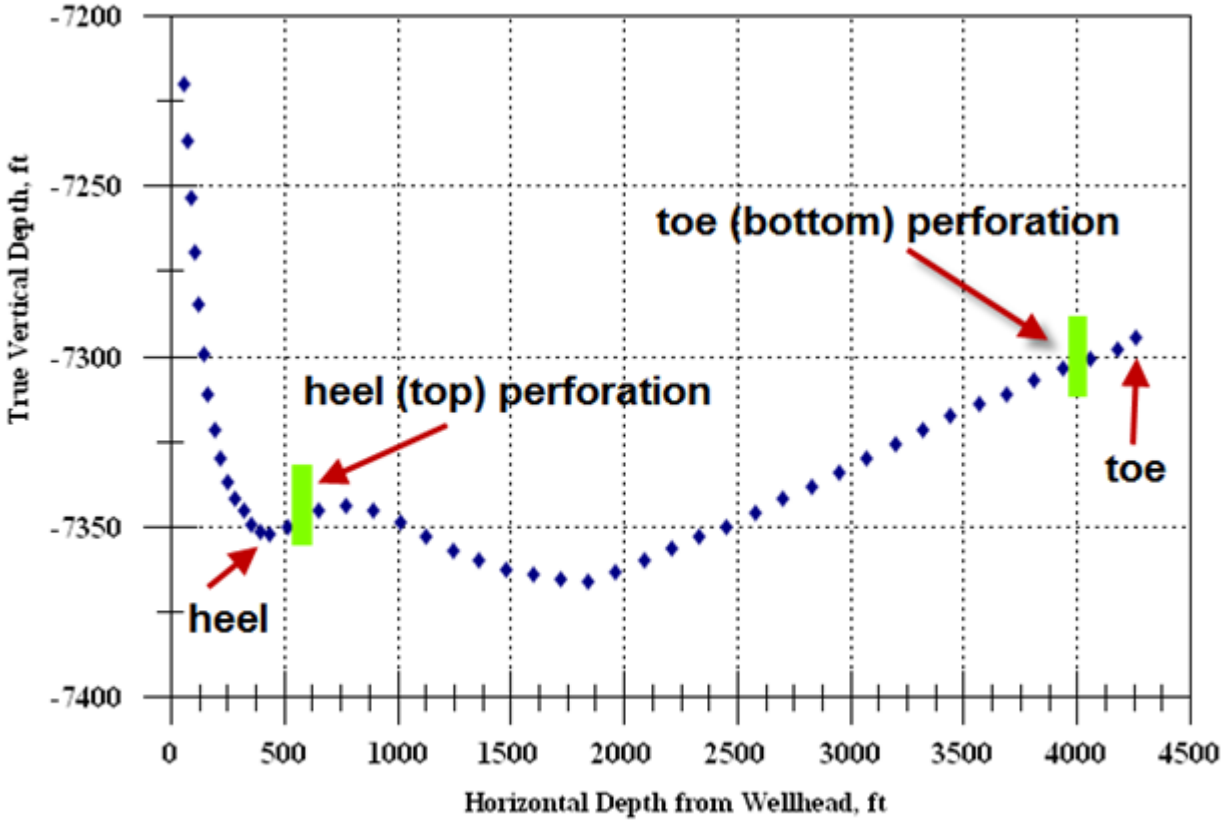


Figure 5 – Representative Barnett wellbore path in the horizontal section.

Tarrant / Johnson County Area of Interest

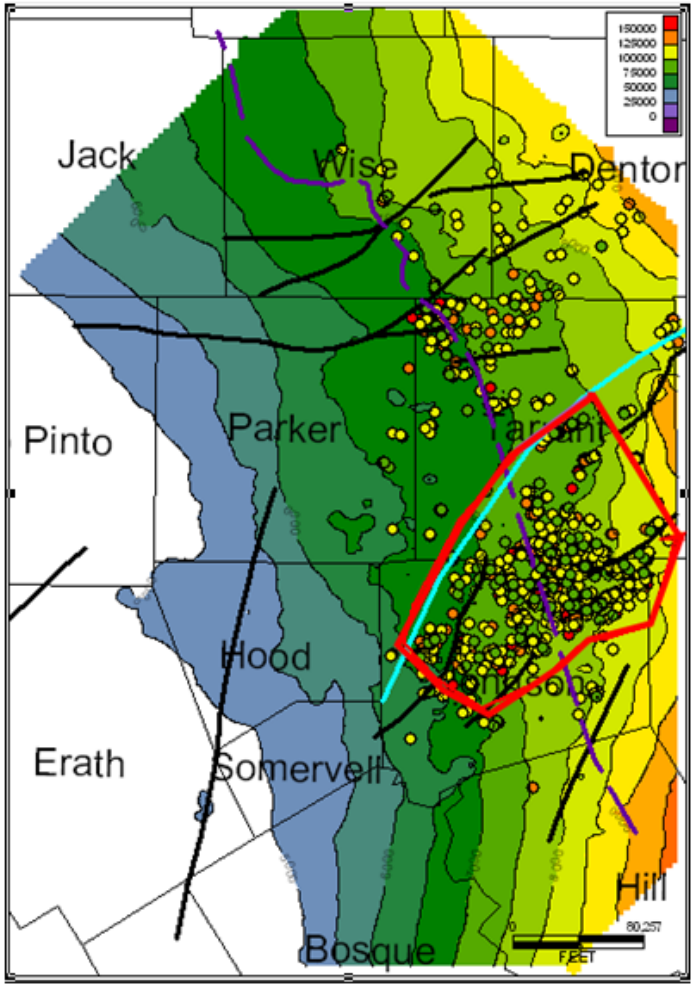


Figure 11 – Location of the Top 10 Percent of peak producers and T/J AOI

Tarrant / Johnson County Area of Interest

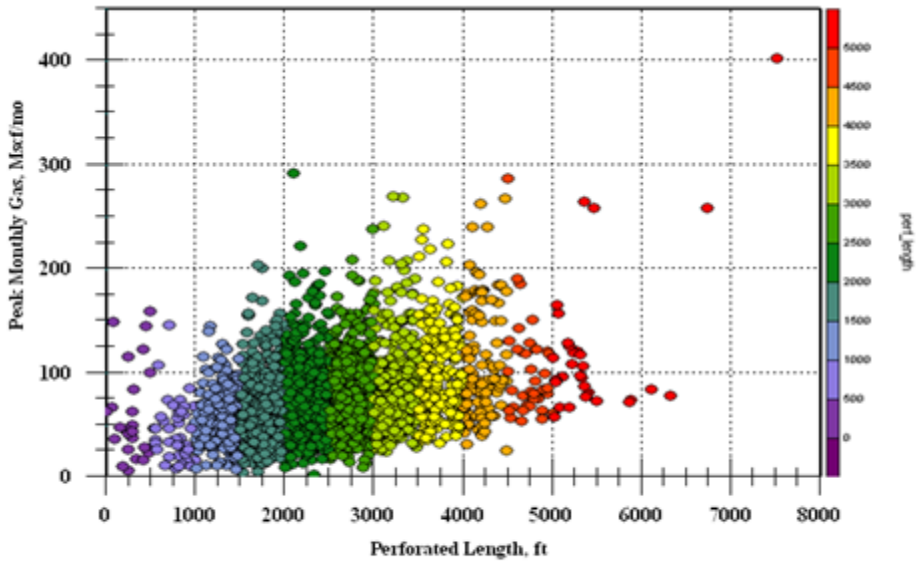


Figure 12 –Peak Gas vs. Perfed Length For 2329 wells in T/J AOI

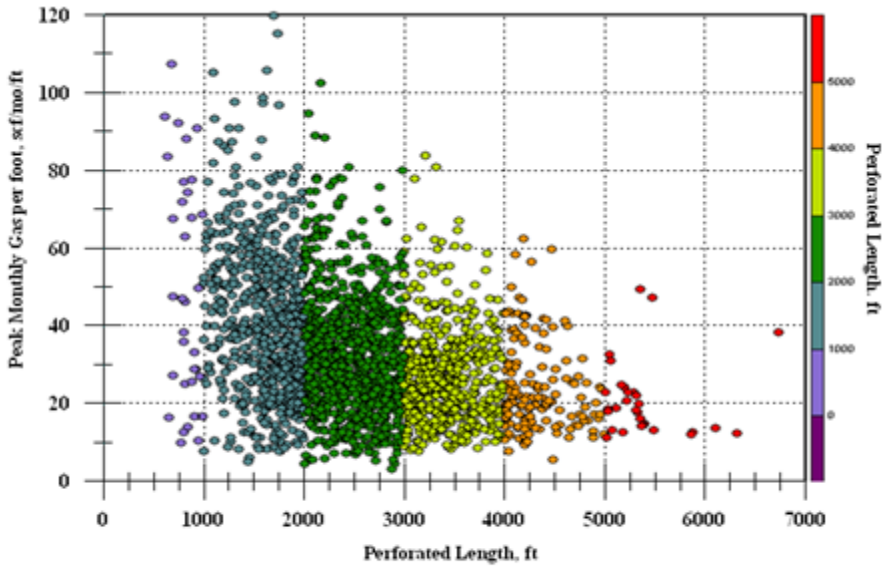


Figure 13 – Peak gas per Perfed ft For 2320 wells in T/J AOI

Peak Gas vs Azimuth

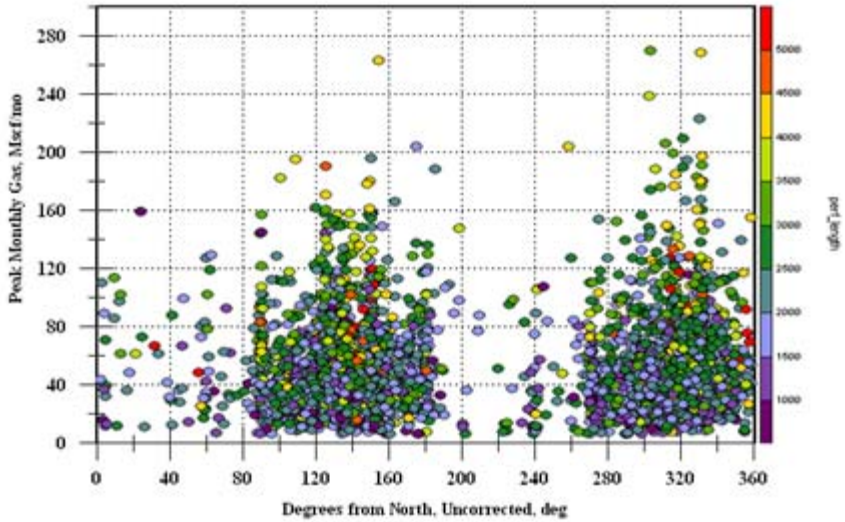


Figure 17 - Peak Gas vs. Horizontal Azimuth for all Barnett

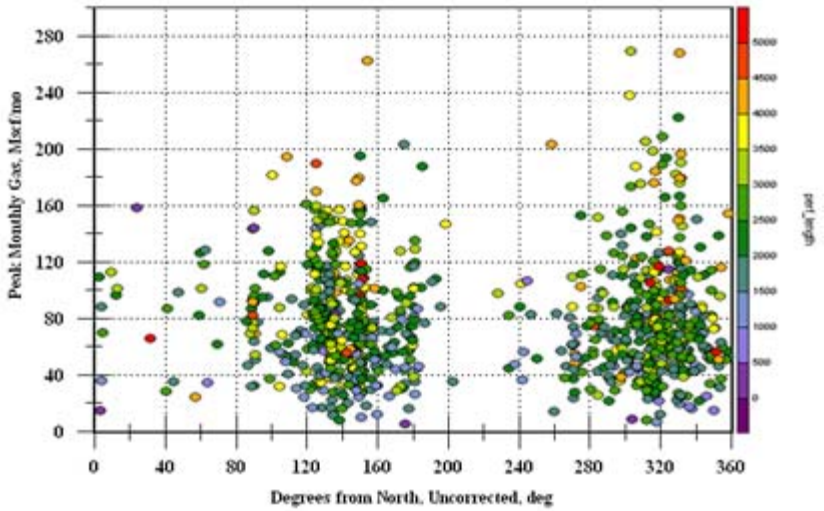


Figure 18 – Peak Gas vs. Horizontal Azimuth for T/J AOI

Larger Treatments May Yield Increased Production

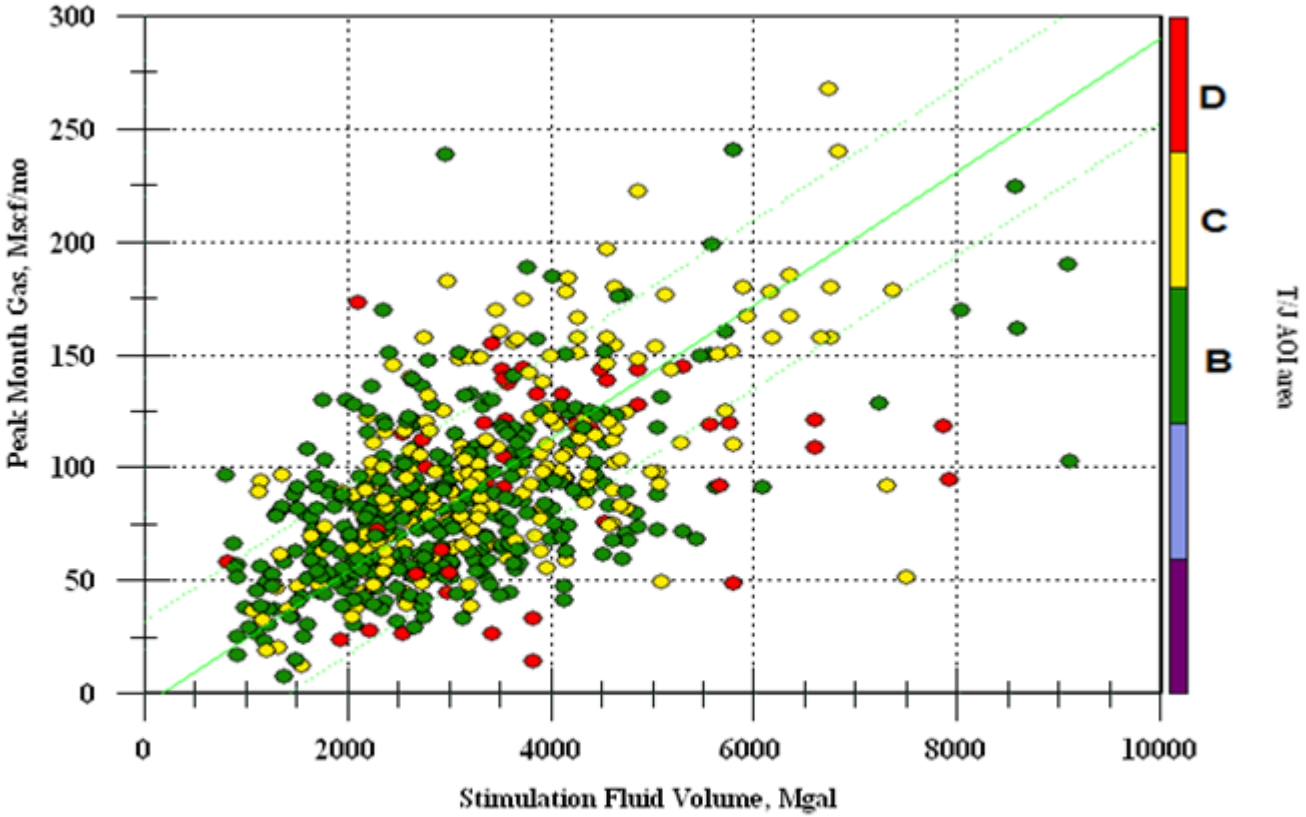


Figure 16 – Peak Mo Gas vs. Stimulation Fluid Volume In T/J AOI after removing top 25 pct 1 yr WGR, R=0.56

Peak Gas vs Drift Angle

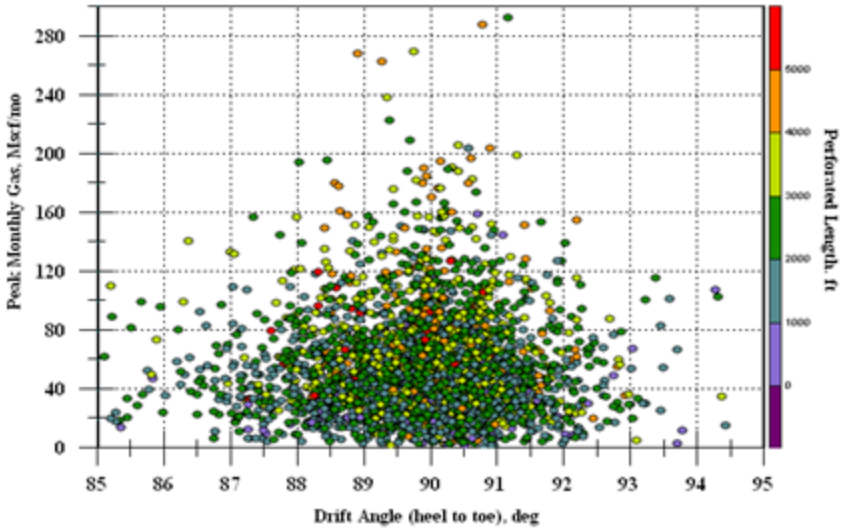


Figure 19 - Peak Gas vs. Drift Angle for all Barnett (3297 wells)

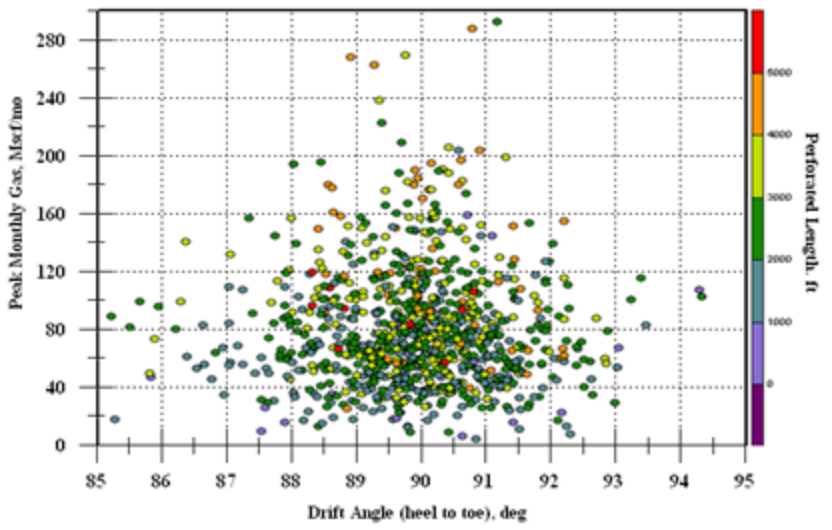


Figure 20 – Peak Gas vs. Drift Angle for T/J AOI (933 wells)

Effect of well bore undulation

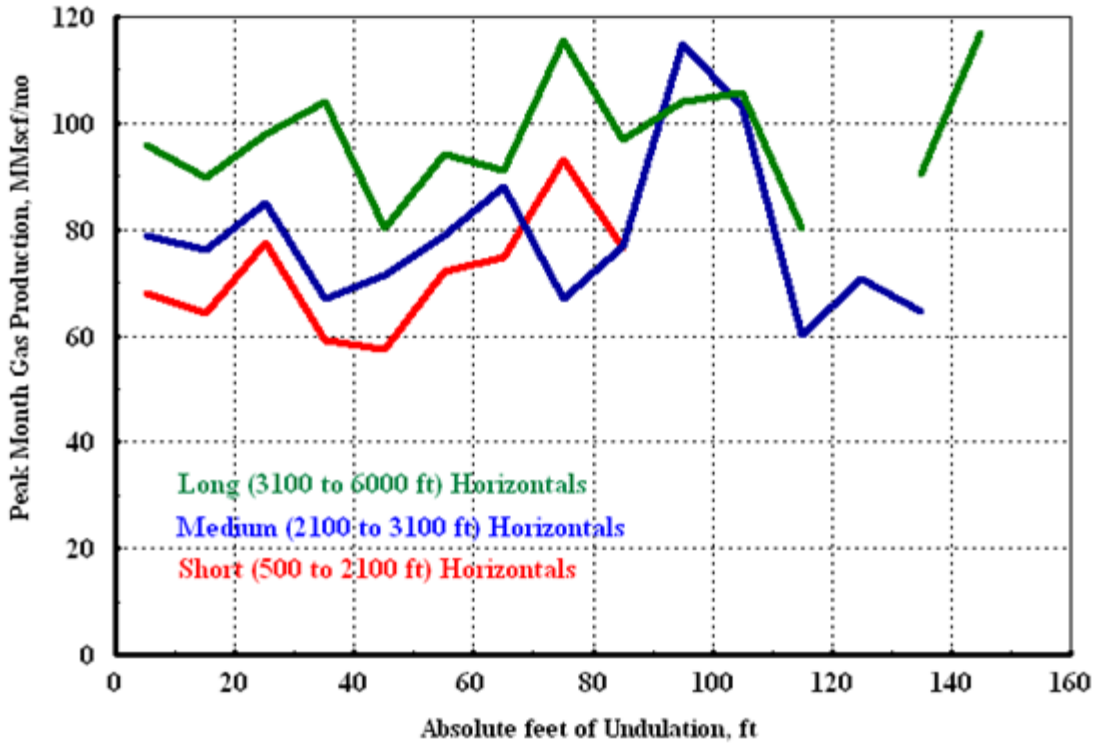


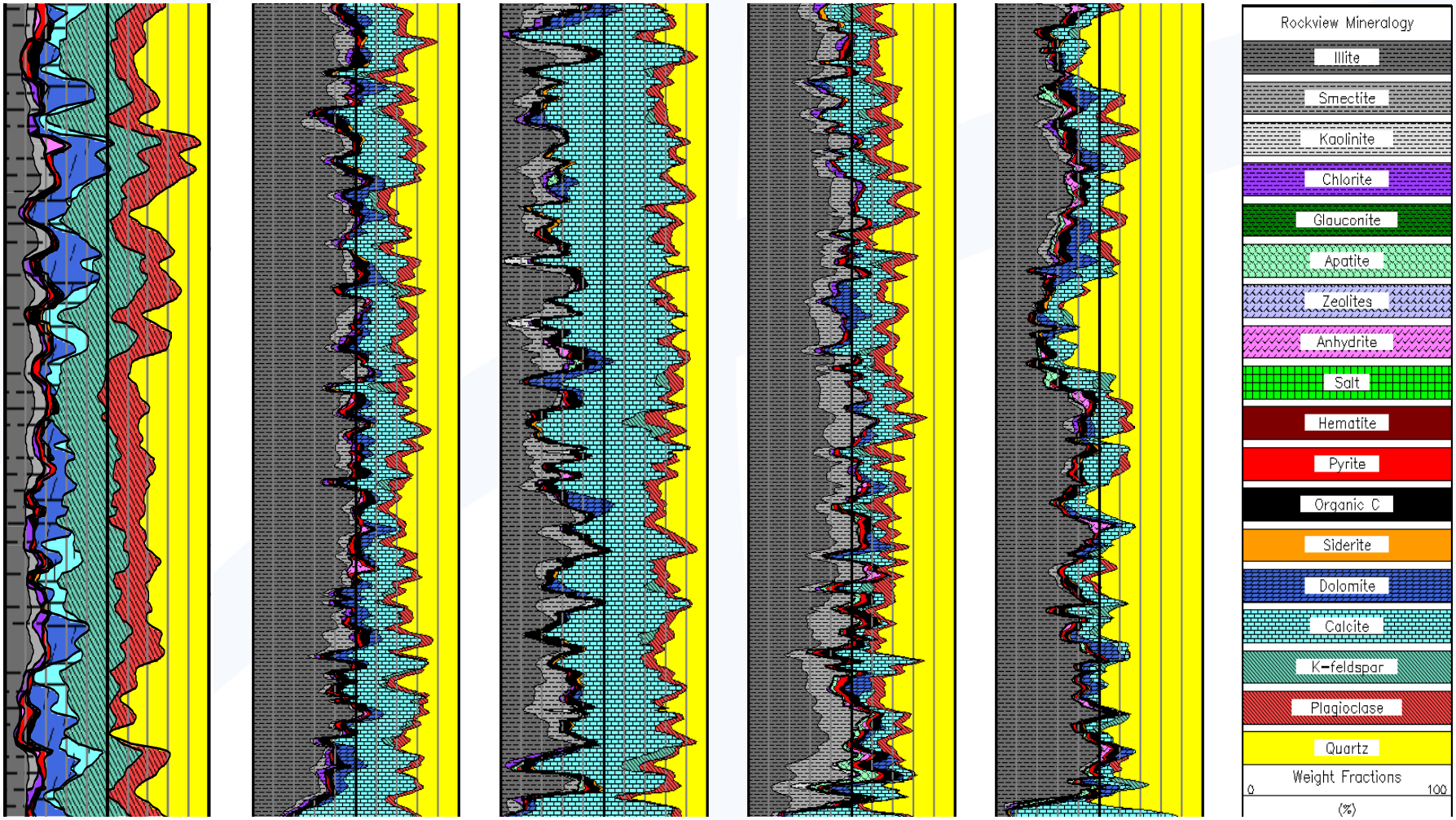
Figure 23 - Peak Monthly Gas for Varying Horizontal Well Lengths as a Function of Absolute Feet of Undulation, Wells in the T/J AOI

Conclusions

- Success of the geographical approach.
- Horizontal lengths greater than 3500-4500 feet are less efficient.
- More successful Barnett wells are drilled on +- 140 / 320 degree azimuths.
  - This is not the preferred azimuth for all Barnett locations!
- Best Barnett producers are drilled nearly flat.
- Barnett wells are distributed evenly toe-up / toe-down.
- Undulations in T/J AOI do not measurably reduce productivity during early well life.

Strong mineralogy variations

Montney | **Haynesville** | **Eagle Ford** | **Marcellus** | **Barnett**



Key Reservoir Parameters

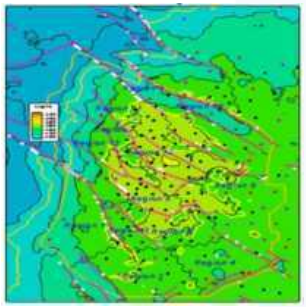
- Brittle Rock – **Helps maximize extent of induced fracture network**
  (Brittle Rock will fracture like glass = better SRV)
- Stress Regime – **Relates to pattern orientation and well spacing**
- Over-pressure
- Local Lithology Variations
- Faults, Karsts, Water

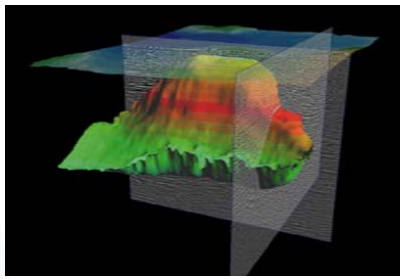
Relates to well productivity

- Organic Content
- Micro-porosity

Total Porosity increases at higher TOC
Relates to gas in place
TOC decreases at higher R_o

- Thermal Maturity ($\mathbf{R_o}$) - **>Mature = Dry Gas <Mature = Wet Gas**





Critical Production Drivers: Reservoir Quality

- **GIP**
  - **$G_i = AhFS_g/B_{gi}$**
    - **Bg = 0.0283 ZT/p**

- **Deliverability**

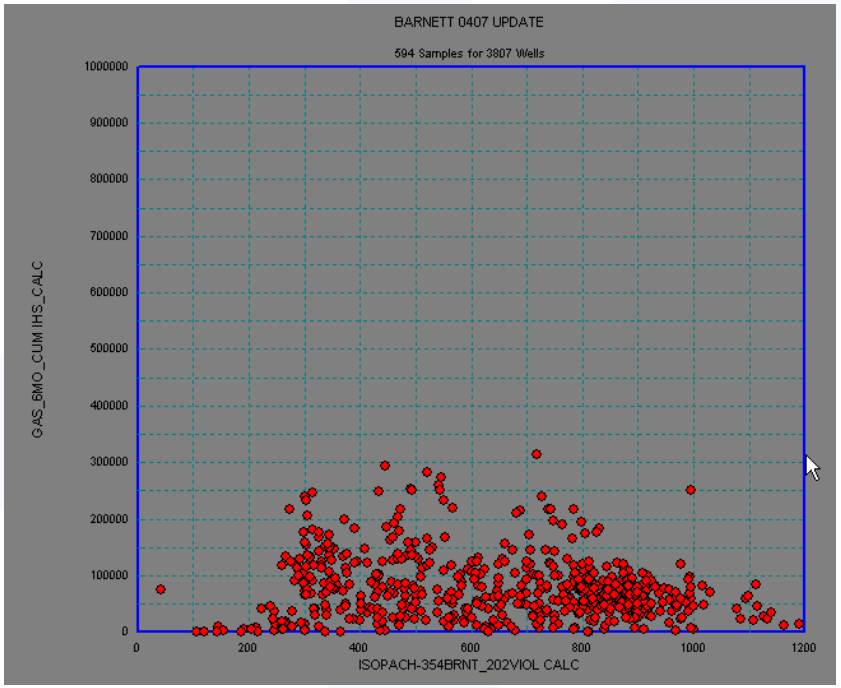
$$q \approx \frac{2\Pi kh(P_{r\,es} - P_{wf})}{u[\ln(r_e / r_w) + S]}$$

Permeability (the second most abused number in the oil patch)

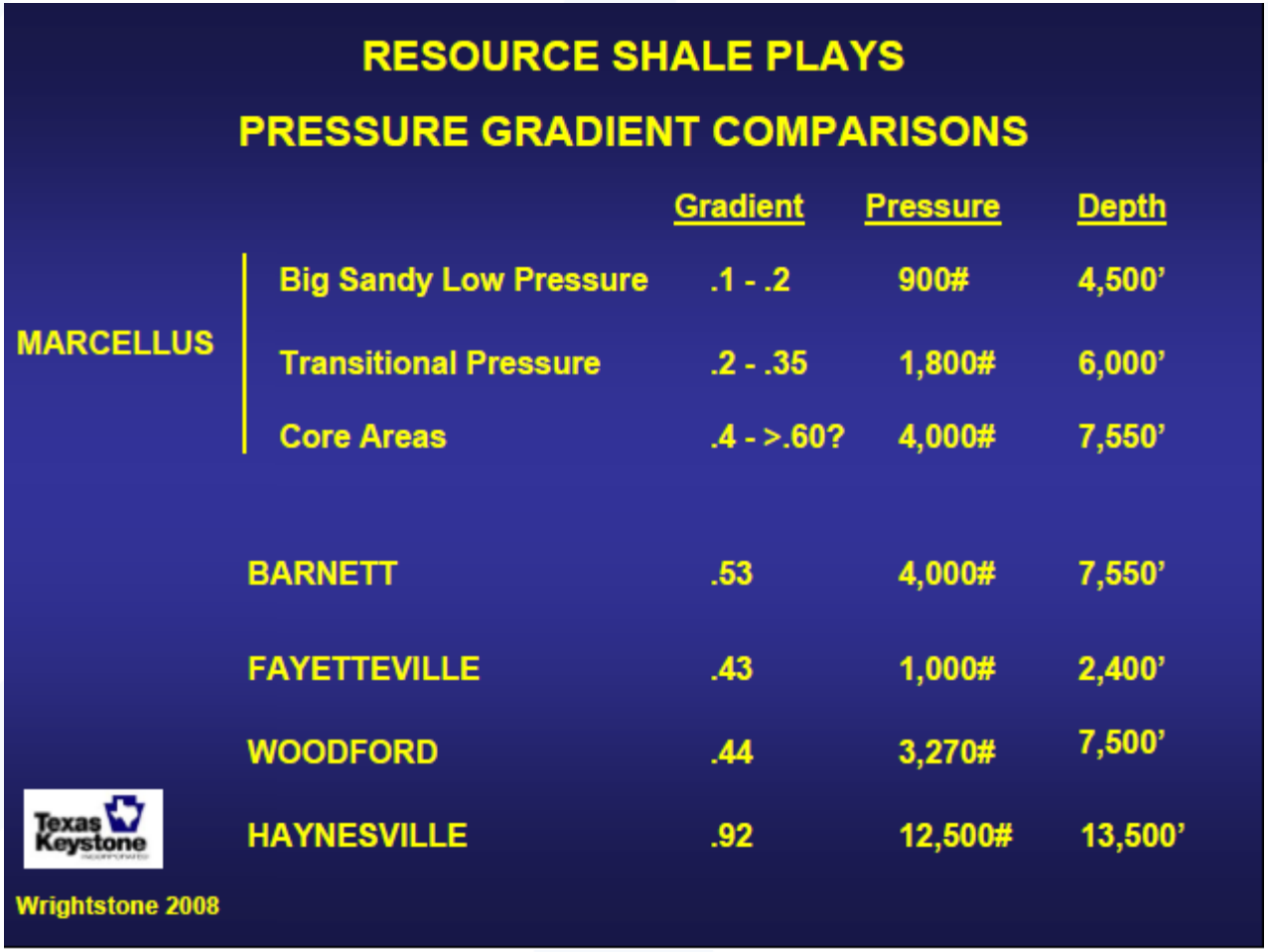
- Matrix K 10^{-7} to 10^{-9} D widely quoted
- Natural fractures controversial
  - Mainly sealed by calcite in Brnt and other gas shales
  - May be open or closed in Bakken, Monterey
- Three data points
  - Gas molecule movement may only be on the order of 10 feet in the lifetime of a well, first modeled by Dr. Mohan Kelcar, Univ. of Tulsa
  - Dr. Chunlou Li, Baker Hughes, modeled 1.5 – 10 feet/year over 1 – 1000 nD perm range
  - Nexen unconventional team modeled 1 m/year
- Implies that complex hydraulic fracturing is a requirement

Thickness

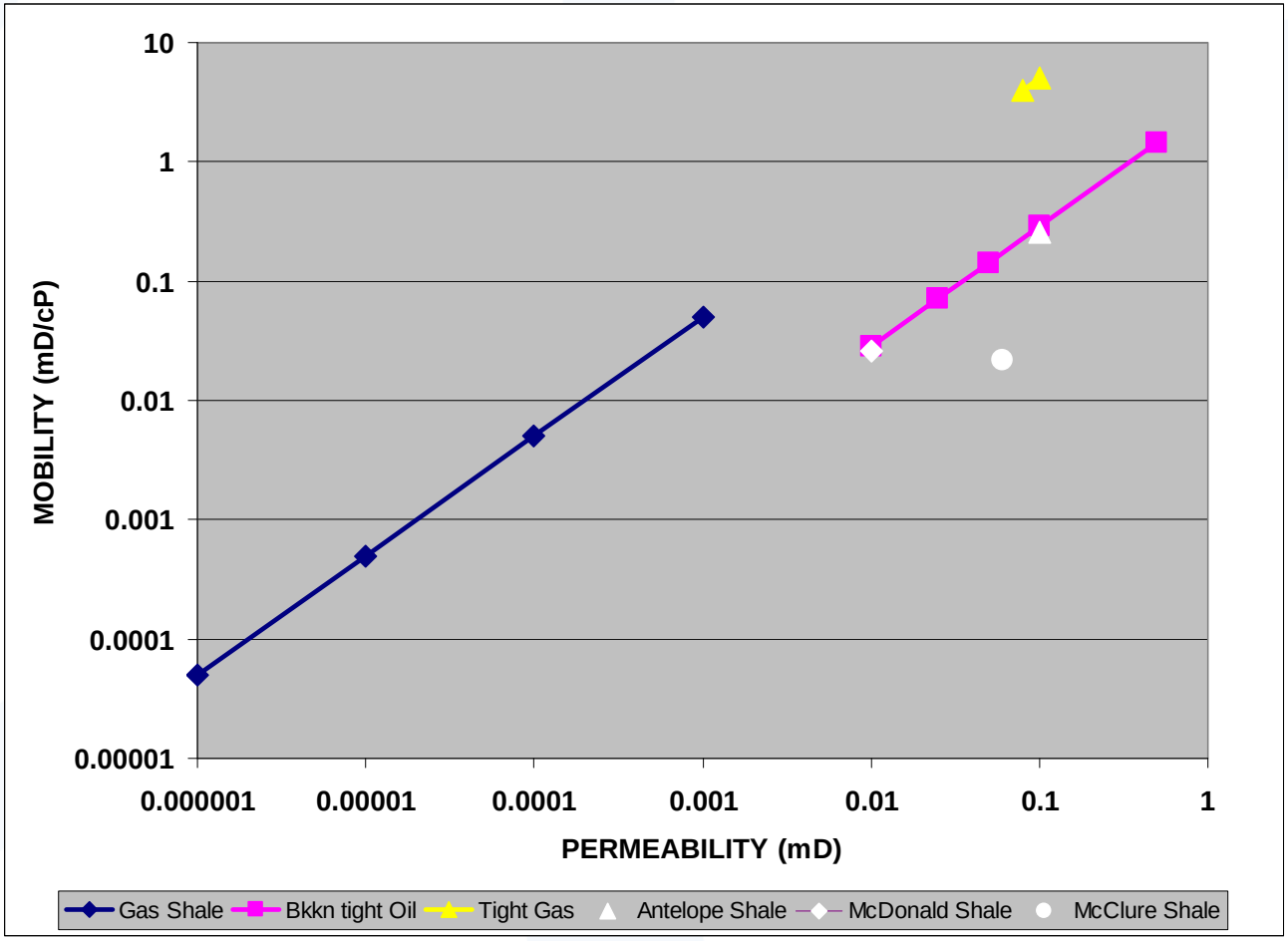
- H is a critical driver in Brnt reservoir quality
  - Both for rate and storage



Pressure Gradient – the no-brainer



Mobility is a Critical Driving Issue



Drainage Radius (R_e)

- Is what you touch with the frac
- See slide 14
- The most abused number in the oil patch, IMHO

Summary

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Acknowledgements

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Thank You!